

CLAIMS

What is claimed is:

1. A mask illumination method, comprising:

illuminating a lithographic mask with a source of light from different directions such that intensities of a plurality of incident beams of light provide a largest possible integrated process window defined in terms of an allowed range for defining shapes, comprising imposing, through application of at least one set of constraints, a first set of intensity parameters for representing maximum possible intensities that can be permitted for overexposed tolerance positions and a second set of intensity parameters for representing minimum possible intensities that can be permitted for underexposed tolerance positions; defining, for each of a plurality of different focal ranges, at least one parameter for each of the first set and the second set; and, determining optimum source intensities using a linear program and constraints that comprise at least said one set of constraints, where the determined optimum source intensities maximize an integrated range of dose and focal variations without causing printed shapes to depart from the allowed range.

2. A method as in Claim 1, where boundaries of the process window impose shape limits corresponding to at least one of underexposed and overexposed conditions.

3. A method to conform a projected pattern to a range of shapes within a maximized total range of defocus positions and exposure doses, the method comprising:
- illuminating a set of mask patterns from a plurality of source directions each having adjustable intensity,
 - projecting an image of the mask patterns from each of the source directions onto an adjustable total range of defocused planes,
 - establishing proportionalities between the adjustable source intensities and the projected intensities along the darkest boundaries of the range of shapes,
 - establishing proportionalities between the adjustable source intensities and the projected intensities along the brightest boundaries of the range of shapes,
 - constraining a limiting intensity parameter in each of the defocused planes to the maximum projected intensity along the darkest boundaries of the range of shapes,
 - constraining a second limiting intensity parameter in each of the defocused planes to the minimum projected intensity along the brightest boundaries of the range of shapes,
 - constraining the first limiting intensity parameter in each particular defocused plane to the maximum of the maximum intensities within the range of defocus positions bounded by the particular defocused plane,
 - constraining the second limiting intensity parameter in each particular defocused plane to the minimum of the minimum intensities within the range of defocus positions bounded by the particular defocused plane,

determining the values of the adjustable source intensities and the total range of defocus planes which maximize the difference between the sum of the maxima of maximum intensities and the sum of the minima of minimum intensities, and

adjusting the adjustable source intensities to the difference-maximizing values.

4. A method as in Claim 3, where the mask patterns are deployed together on a single mask, and where the plurality of source directions illuminate the mask simultaneously.
5. A method as in Claim 3, where the mask patterns are deployed on at least two masks, and where a first portion of the projected image is formed by illuminating a first mask with a first portion of the illuminating source directions, and where at least one additional portion of the projected image is formed by projecting at least one additional mask from at least one additional portion of the illuminating source directions.
6. A method as in Claim 3, where the mask patterns are deployed on at least two separate mask regions, and where a first portion of the projected image is formed by illuminating a first mask region with a first portion of the illuminating source directions, and where at least one additional portion of the projected image is

formed by projecting at least one additional mask region from at least one additional portion of the illuminating source directions.

7. A method to obtain an illumination source solution for illuminating at least one mask for printing a pattern defined by the at least one mask, comprising:
 - supplying mask shapes and an allowable range of printed shapes;
 - determining sample points;
 - using a source pixelation, determining proportionalities between source intensities and sample point intensities, for individual ones of a plurality of focal planes;
 - determining a maximum allowable intensity at dark sample points, and a minimum allowable intensity at bright sample points;
 - constraining a first intensity parameter in each focal plane to a maximum intensity among sample points at dark boundaries of the shape range;
 - constraining a second intensity parameter in each focal plane to a minimum intensity among sample points at bright boundaries of the shape range;
 - constraining the first intensity parameter in each focal plane to a maximum intensity bound within a truncated focal range;
 - constraining the second intensity parameter in each focal plane to a minimum intensity bound within the truncated focal range; and
 - executing a focal range loop, comprising
 - selecting an initial defocus limit;

maximizing a difference between a sum of the bounded maximum intensities and a sum of the bounded minimum intensities; and

iterating by increasing the defocus limit so long as the constraints are met, otherwise terminating the focal range loop and outputting a result that provides a maximum difference between the sum of the maximum intensities and the sum of the minimum intensities.

8. A system for illuminating a mask, comprising means for illuminating a photolithographic mask with light from different directions such that intensities of a plurality of incident beams provide a largest possible integrated process window defined in terms of an allowed range for defining shapes, said illuminating means comprising means for imposing, through application of at least one set of constraints, a first set of intensity parameters for representing maximum possible intensities that can be permitted for overexposed tolerance positions and a second set of intensity parameters for representing minimum possible intensities that can be permitted for underexposed tolerance positions; means for defining, for each of a plurality of different focal ranges, at least one parameter for each of the first set and the second set; and means for determining optimum source intensities using a linear program and constraints that comprise at least said one set of constraints, where the determined optimum source intensities maximize an integrated range of tolerable dose and focal variations without causing printed shapes to depart from the allowed range.

9. A system as in Claim 8, where boundaries of the process window impose shape limits corresponding to at least one of underexposed and overexposed conditions.
10. A system as in claim 8, where the mask is used to project patterns onto a wafer.
11. A computer program stored on a computer readable media, comprising program code to conform a projected pattern to a range of shapes within a maximized total range of defocus positions and exposure doses, said program code controlling operation of a system for illuminating a set of mask patterns from a plurality of source directions each having adjustable intensity, projecting an image of the mask patterns from each of the source directions onto an adjustable total range of defocused planes, establishing proportionalities between the adjustable source intensities and the projected intensities along the darkest boundaries of the range of shapes, establishing proportionalities between the adjustable source intensities and the projected intensities along the brightest boundaries of the range of shapes, constraining a limiting intensity parameter in each of the defocused planes to the maximum projected intensity along the darkest boundaries of the range of shapes, constraining a second limiting intensity parameter in each of the defocused planes to the minimum projected intensity along the brightest boundaries of the range of shapes, constraining the first limiting intensity parameter in each particular defocused plane to the maximum of the maximum intensities within the range of defocus positions bounded by the particular defocused plane, constraining the

second limiting intensity parameter in each particular defocused plane to the minimum of the minimum intensities within the range of defocus positions bounded by the particular defocused plane, determining the values of the adjustable source intensities and the total range of defocus planes which maximize the difference between the sum of the maxima of maximum intensities and the sum of the minima of minimum intensities, and adjusting the adjustable source intensities to the difference-maximizing values.

12. A computer program as in Claim 11, where the mask patterns are deployed together on a single mask, and where the plurality of source directions illuminate the mask simultaneously.
13. A computer program as in Claim 11, where the mask patterns are deployed on at least two masks, and where a first portion of the projected image is formed by illuminating a first mask with a first portion of the illuminating source directions, and where at least one additional portion of the projected image is formed by projecting at least one additional mask from at least one additional portion of the illuminating source directions.
14. A computer program as in Claim 11, where the mask patterns are deployed on at least two separate mask regions, and where a first portion of the projected image is formed by illuminating a first mask region with a first portion of the

illuminating source directions, and where at least one additional portion of the projected image is formed by projecting at least one additional mask region from at least one additional portion of the illuminating source directions.

15. A computer program stored on a computer readable media, comprising program code to obtain an illumination source solution for illuminating at least one mask for printing a pattern defined by the at least one mask, comprising a program code segment, responsive to predetermined mask shapes, an allowable range of printed shapes and an illumination source pixelation, to determine sample points; to determine proportionalities between source intensities and sample point intensities for individual ones of a plurality of focal planes; to determine a maximum allowable intensity at dark sample points, and a minimum allowable intensity at bright sample points; to constrain a first intensity parameter in each focal plane to a maximum intensity among sample points at dark boundaries of the shape range; to constrain a second intensity parameter in each focal plane to a minimum intensity among sample points at bright boundaries of the shape range; to constrain a third intensity parameter in each focal plane to a maximum intensity bound within a truncated focal range; to constrain a fourth intensity parameter in each focal plane to a minimum intensity bound within the truncated focal range; and to execute a focal range loop to obtain a defocus limit that represents a maximum difference between the minimum and maximum intensities.

16. A computer program as in Claim 15, where the computer program code for the focal range loop comprises program code to select an initial defocus limit; to maximize a difference between a sum of the bounded maximum intensities and a sum of the bounded minimum intensities; and to iterate by increasing the defocus limit so long as the constraints are met, and to otherwise terminate the focal range loop and output a result that provides a maximum difference between the minimum and maximum intensities.
17. A method for minimizing a loss in an integrated process window, the loss resulting from perturbations in a plurality of masks, each mask containing features for printing a common shape, where the perturbations span the range of errors that must realistically be expected when the features are fabricated on a typical mask using a practical mask-making process, the method comprising:
- illuminating each mask with a source of light from different directions according to a common window, wherein illumination is such that intensities of incident beams of light provide a largest possible integrated process window for printing the common shape within the allowed range using each perturbed mask, with the same exposure and focal range used for each mask, the integrated process window defined in terms of an allowed range for defining the common shape, wherein the largest possible integrated process window comprises an integrated range of dose and focal variations for printing the common shape without causing the printed common shape to depart from the allowed range.

18. A method as in claim 17, where defining the largest possible integrated process window comprises:

imposing, through application of at least one set of constraints, a first set of intensity parameters for representing maximum possible intensities that can be permitted for overexposed tolerance positions and a second set of intensity parameters for representing minimum possible intensities that can be permitted for underexposed tolerance positions;

defining, for each of a plurality of different focal ranges, at least one parameter for each of the first set and the second set; and,

determining optimum source intensities using a linear program and constraints that comprise at least the one set of constraints, where the determined optimum source intensities maximize an integrated range of dose and focal variations without causing the printed common shape to depart from the allowed range.

19. A method to provide an empirical yield improvement in at least one printed feature produced by a lithographic system, the method comprising:

through application of at least one set of constraints, imposing a first set of intensity parameters for representing maximum possible intensities that can be permitted for overexposed tolerance positions and a second set of intensity parameters for representing minimum possible intensities that can be permitted for underexposed tolerance positions;

defining, for each of a plurality of different focal ranges, at least one parameter for each of the first set and the second set;

determining optimum source intensities using a linear program and constraints that comprise at least the one set of constraints;

specifying a bias that provides for an offset from a critical dimension of a design specification for each printed feature; and,

limiting changes in the source intensities to introduce the bias.

20. The method as in claim 19, wherein the bias compensates for manifestation of a system error in the printed feature.
21. The method as in claim 19, wherein specifying is performed by a system driver.